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ATOMIC SHIPS SAFETY PROBLEMS

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A considerable experience of first civilian nuclear power plants (NPP) for ships has been accumulated up to now , in particular on the "Lenin" icebreaker. In this connection, it is important to anlyze the obtained information from the point of view of the atomic ship safety and to draw conclusions about correctness or shortcomings of the decisions and measures taken before. Taking into account these considerations, some problems of the "Lenin" icebreaker operation safety are analized below.

1. On-board NPP of an Icebreaker is a Reliable Power Source

As known a NPP is potentially hazardeous because of a great quantitiy of radioactive substances within the reactor and in its primary circuits. An accident involving a damage for the primary circuit tightnes and all the more a disturbed hermeticity of fuel element cans may result in an escape (out-side of especially confined zones) of radioactive substances in the quantities which are dangerous for the service personnel attending the plant and even for the population near the plant site. This consideration is of a special importance in case of building a transport NPP, for instance marine NPP's which will be considered below.

In settling the problem of using a NPP for ships of one or an other destination it is necessary to study the possibility of providing a higher reliability of such a ship as some kind of "platform" for accomodation of a potentially hazardeous NPP.

This condition make it necessary to analyze the statistical data about accidental situations with seagoing ships relating both the average number of such events and the causes and sites of their occurence.

First of all attention must be payed to the number of accidents caused by contact damage and ship collisions, by strandings, by damage to machinery , by fires and explosions, by weather damage (gales and storms) and other causes. The corresponding data are given in Table I. It follows from them that every third ship having a gross tonnage more than 500 register gross tons (rgt) is damaged practically every year.

Of course, from the point of view of maintaining the on-board NPP integrity, the most dangerous accidents happen in the cases involving ship collisions, fires and explosions as well as casualties due to gales and storms. The data in Table 2 where the causes of accidents are analyzed indicate that the number of such events is very great. For instance, from 8 000 ships having been met with accident last year (1963) 1814 ships or 22.6% were damaged because of collisions and 1615 (20.2%) due to contact damage; in 1398 cases (17.5%) falures of machniery shafts and propellers took place; 1049 ships (13.1%) run against underwater obstacles; 792 ships (9.9%) were damaged by gales and storms; on 439 ships (5.5%) were burnt down and exploded, and more than 900 ships (11.2%) were wrecked because of unknown reasons (including those which were missing and sunken). Table 2 contains data for 1959-1963. The statistical data about casuality returns in the world fleet for previous years (1948-1958) are analogous to the presented above.

The information about losses of world's merchant ships in 1948-1962 (according LLoyd's Register (7) for ships with cargo capacity exceeding 100 rgt) is given in Table 3. It should be noted that the mentioned statistics does not include surface and underwater warships. As is evident from this table some 160-250 ships having capacities 100 rgt and more are tatally lost every year which makes up 0.5-0.9% of total number of world's merchant fleet and 0.25-0.35 % of world tonnage. The data in Table 4 illustrate the fact that loses is an event of a sufficiently great probability even for large ships of important capacity; this type danger is more imminent for atom-powered ships. A very interesting information material is given in Table 5 where causes of ship losses are indicated according to Lloyd's Register (8). As is shown, the primary causes of the loss in 1958-1962 are the running-agrounds (40-50%), sinkings (25-30%), collisions (10-13%) and fires and fires and explosions (10-20%). Analogous figures were also obtained from Lloyd's Register tables for the previous years (1948-1957).

Table I

Accident rate on world's merchant fleet in 1948-1963 (according to The Liverpool Underwriters Association (5) data about ships with capacities exceeding 500 rgt)

	Number of ships on world's merch.fleet	Number of ships lost particial or total	Percentage lost
1948	16 340	7 729	42.3
1949	17 227	7 063	41.0
1950	18 052	6 873	38.1
1951	18 426	7 789	42.3
1952	18 661	7 776	41.7
1953	18 997	7 269	38.3
1954	19 658	7 014	35.6
1955	19 743	-	-
1956	20 289	-	-
1957	20 926	7 333	35.1
1958	21 924	6 944	31.7
1959	22 531	7 359	32.6
1960	22 621	7 368	32.6
1961	23 892	7 818	32.7
1962	24 243	7 938	32.7
1963	24 603	8 008	32.5

Very important is the fact that in spite of the continuously increasing equipment of ships with modern navigational instruments and the increasing utilization of shore installations for warning the ships against dangers the number of ship wrecks remains actually on a constant level (9).

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Table II

Number of ships damaged in 1959-1963 (according to The Liverpool Underwriters Association (6) data for ships with capacities 500 rgt and more)

Causes	1959		1960		1961		1962		1963	
	Number of ships	%	Number of ships	%	Number of ships	%	Number of ships	%	Number of ships	%
Contact damage	1 683	22.9	1 675	22.7	1 753	22.4	1 594	20.1	1 615	20.2
Collisions	1 600^{x}	21.7	1 500^{x}	20.4	1 600^{x}	20.5	1 818	22.9	1 814	22.6
Damage to machinery	1 229	16.7	1 337	18.1	1 401	17.9	1 362	17.2	1 398	17.5
Strandings	989	13.4	1 023	13.9	954	12.2	993	12.5	1 049	13.1
Weather damage	772	10.5	739	10.0	844	10.8	826	10.4	792	9.9
Fires and explosions	428	5.8	419	5.7	470	6.0	454	5.7	439	5.5
Others	658	9.0	675	9.2	796	10.2	891	11.2	901	11.2
Total	7 359	100	7 368	100	7 818	100	7 938	100	8 008	100

__Note:__ Approximately. Together with contact damage the sum is correct .

Table III

Totally losses of world's merchant fleet in 1948-1962 (according to LLoyd's Register data (7) for ships with gross capacities 100 rgt and more)

	Number of lost ships	Percents of world fleet	Capacities, 10^3 rgt	Percents of world tonnage
1948	196	0.67	222.5	0.27
1949	220	0.94	244.1	0.30
1950	222	0.72	260.0	0.31
1951	218	0.70	290.9	0.33
1952	188	0.60	250.2	0.28
1953	226	0.71	322.2	0.35
1954	182	0.56	262.4	0.27
1955	178	0.55	254.7	0.25
1956	163	0.49	248.5	0.24
1957	163	0.48	270.9	0.25
1958	160	0.46	347.5	0.29
1959	181	0.50	281.5	0.23
1960	171	0.47	358.2	0.28
1961	189	0.50	471.1	0.35
1962	249	0.64	481.1	0.34

Table IV

Tonnage distribution of ships damaged in 1960 and 1961

Capacities, rgt		500-4999	5000-9999	More than 10 000
Sunken ships	1960	12	3	2
	1961	13	4	–
Accidents involving fires, explosions, collisions and strandings	1960	54	10	6
	1961	33	28	11
Total	1960	66	13	8
	1961	46	32	11

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Table V

Number of merchant ships totally lost in 1958–1962 (according to The Lloyd's Register data for ships with capacities more than 100 rgt)

	1958		1959		1960		1961		1962	
	Number of ships	%	Number of ships	%	Number of ships	%	Number of ships	%	Number of ships	%
Wrecked	56	35.0	73	40.3	72	42.2	80	42.3	123	49.5
Foundered	48	30.0	60	33.1	50	29.2	43	22.8	64	25.7
Fires & explosions	15	9.4	14	7.7	17	9.9	35	18.5	24	9.6
Collisions	23	14.4	22	12.2	19	11.1	23	12.2	16	6.4
Missings	2	1.2	3	1.7	7	4.1	1	0.5	11	4.4
Others	16	10.0	9	5.0	6	3.5	7	3.7	11	4.4.
Total	160	100	181	100	171	100	189	100	249	100

Foundering of a nuclear powered ship is a particular danger since it entails an eventual contamination of sea bottom layers with longlived radioactive substances which may penetrate into sea plants and animals, and through the food chains into human bodies.

An accident with an nuclear-powered ship far from settlements and busy shipping routes is undubtedly less dangerous in its nature. Unfortunately investigations show that emergency situations usually take place close by seaports. So, the published analysis of collisions and foundering of sea-going ships in 1955-1961 shows that the most probable localities for such events are the harbour approaches and roadsteads (66% of all cases). Only 8%of ship collisions in these years occured on the high seas (10).

All the facts stated above compel us to take maximum care when choosing the type of ships on which nuclear power plants may be installed. It should be kept in mind that in case of sinking of such a ship in the vicinity of a sea port or a narrow strait the latter must be closed for an indefinite period of time. The damage caused by closing a port or strait is not yet evaluated, but evidently it will be quite essential.

In the light of the above statements one may understand the once taken decision: until a sufficient experience of operation of civil ship NPP's, to use them on icebreakers for which the probability of being sunk is exceptionally small. It is characteristic that according to world's statistics there was no arctic icebreaker among the more than 2 000 ships tottaly lost in the last 15 years.

Thus, an icebreaker is the most reliable "platform" securing the vitality of a nuclear power plant in any operating conditions.

As noted elsewhere (1) the hull of "Lenin" icebreaker is quite strong to endure any ice pressure that is possible in Arctic. The hull is devided into tvelve compartments by eleven main transverse water-tight bulkheads. The unsinkability of the icebreaker is ensured even with two adjacent compatrments being flooded simultaneously.

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Thanks to tho especially strong hull the icebreaker is out of usual dangers: collisions with other ships, compression in ice drifts or running aground.

It is not without interest, in the aspect under consideration, to cite the following case from the operating experience with the "Lenin" icebreaker.

On 12 October 1961 the icebreaker was passing the Sannikov strait making 17 knots through a finely broken thin ice and run against an iceberg sunken down to the bottom. The ice resistance was so high that as a result of the collision the icebreaker fully lost its speed and stuck on the underwater obstacle, taking a list to the starboard. Later on when the icebreaker has been get off the ice and was afloat again a large mass of ice debris appeared on the port side, and bord compartment (between transverse bulkneads 36 and 48 of the frame) was flooded. The inner space of the ship were undamaged since practically at full length of the ship there was provided so called second board consisting of fore-and-aft watertight bulkheads. In the vicinity of the NPP they are one fifth of ship's width away from the outer skin. The hazard of a great list due to flooding of board compartments is excluded owing to the waterducts between them which, in case of skin damage, makes for the floding of compartments on the other board symmetrically relative to ship's diametral plane.

In spite of the damage the icebreaker continued its normal functioning in Arctic some more weeks (one month and a half) after the collision. Examination of the ship in a dock has shown that the outer skin had a dent (almost at full length of the ballast compartment) with maximum sag 250 mm and with ruptures at this spot (Fig.1). Thus, the collision confirmed the high strength of the hull and the optimal - from the point of view of unsinkability - distribution of watertight compartments provided in the design of the "Lenin" icebreaker.

A collision of the icebreaker with other ships will hardly result in its loss. A theoretical estimation of consequences was made for the most dangerous case, i.e. for collision with the transport icebreaker-type ship "Lena" having a very strong hull and running speed 15 knots with 11 000 tons

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displacement in conditions where the icebreaker "Lenin" should be struck at right angles to its board opposite the place occupied by the NPP.

It was found that even with a blow delivered by the transport iceship "Lena" at full speed the damage to icebreaker's board will not affect the compartment where the radiation hazardous equipment is accomodated (Fig.2).

The above statements confirm the sufficience of the measures taken for keeping the icebreaker "Lenin" afloat and for protecting the NPP from destruction in the eventual cases of navigational damage.

Both during the collision of the icebreaker with fixed ice and in conditions of pitching or rolling, of long-lasting vibrations and continuous shakes when the ship's hull strikes against ices, the NPP functionned uniterruptedly. With a view to secure the NPP safety on the icebreaker an automatic system is provided to stop the chain reactions in reactor core at inadmissible excursions of one or more especially important parameters from specified values. As shown by the experience with operation of the NPP on "Lenin" icebreaker(Table 6) such events on shop reactors are not excluded.

The satisfactory results of long-time operation of the NPP on "Lenin" icebreaker under complicated conditions of mechanical coertions allow to suppose that nuclear reactors on a ship are reliable power sources.

Table VI

Occurence of automatic of emergency rod tripping (safety trip) during the operation of "Lenin" icebreaker in Arctic

Reactor number	I	2	3
Power drops have taken place after operation during	32.8; 36.2;46.0; 88.9; 115.2 effective days[x] for the first campaign,and 14.3 effective days for the second campaign.	27.6; 32.6 and 45.3 effective days for the first campaign,and 15.7; 26.I and 86.3 effective days for the second campaign.	17.0; 17.6; 17.8; 45.0; 83.2; 83.3 and 195 effective days for the first campaign,and 18.7 effevtive days for the second campaign.
Summary number of emergency trippings	7	6	8

x) An effective day corresponds to generation of 90 Mw/days.

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II. Atomic Icebreaker "Lenin" Safety for the Environment

After entering into the icebreaking fleet in the end of 1959 the "Lenin" icebreaker has been taking an active part in leading the ships through Arctic ice during the navigation of 1960-1963. During this time it has run about 60 000 miles including 40 000 miles through ice fields. On the Northern Route some 300 ships were conducted with the assistence of "Lenin" icebreaker.

The NPP of "Lenin" icebreaker has proved to be radiation-safe both for the attending staff (II) and for the outer environment. It will be noted that inside fuel elements of each reactor on the icebreaker there are materials the summary activity of which reaches approximately $3.0 \cdot 10^8$ curie. About 10^5 curie of the active materials are outside the pellets of fuel elements made of sintered uranium dioxide. With disturbed integrity of fuel element cladding these active materials may be released into the primary circuit.

In order to prevent the dissimination of radioactive substances outside the primary hermetic circuit all the equipment and pipes of the NPP on "Lenin" icebreaker permanently or periodically filled with active water are accommodated in the compartment of so called central compartment (CC) which is a zone of strong regime. This compartment is isolated from other compartment of the ship by means of hermetic bulkheads. Communications with the central compartment are possible only through a blocking sanitary post observing the appropriate regime and making careful radiometric monitoring. The central compartment has a special open-circuit ventillation system isolated from other systems on the ship. The air from these rooms is drawn out through the mainmast in the aggregate volume about 80 000 m^3 per hour.

The experience with icebreaker tests and operation has shown a sufficient efficacity of such a lay-out of radiation hazardous equipment. The mooring tests of the NPP of "Lenin" icebreaker at powers up to 40% were made within one of the largest cities, in Leningrad. In the vicinity of the test site a wide network of radiometric control points was installed for monitoring the surrounding media, including air, water, plants and animals. The confrontation of the results measured before the tests with the results obtained during the tests and after them has shown that there was no activities exceeding the background values. The most characteristic data are presented in Fig.3 and 4 for beta-active substance concentration in air and in water of the Neva river 12 . From these investigations it was stated that the variations of specific activity levels in atmospheric air, Neva water and hydrobionts in the vicinity of the "Lenin" icebreaker site for June through September 1959 were of a seasonal character, were not connected with the icebreaker position and did not depend on the NPP operation. It is characteristic that in conformity with the seasonal variations of natural activity 13 the greater values of specific activity in air, water and hydrobiont samples were registered before NPP tests.

Analogous conclusions were inferred during running tests of the icebreaker in the Baltic Sea and in the period of its operation on the Northern Route. In this connection it was considered possible to base the atomic icebreaker "Lenin" in the harbour of a large town Murmansk situated in narrows (the Kola strait) with an intense navigation.

During a four-year operation of the icebreaker NPP there were several cases of water leaking from the primary circuits through the connector joints of valves in the drain and feed system. A negligible part of the water was here eveporated, and the steam was spread into the central compartment. Radiometric analyses of the air-steam mixture have shown that its activity is more than by 99.9% determined by the inert-gas radioactive isitopes. Calculations of maximum permissible concentration (MPC) of radioactive contanimations in the auxiliary rooms air based on real compositions of radioactive nuclei in the CC air give values ca. 10^{-9} curie per litre.

With short-term leaks of the first circuit water the integral activity of aerosol long-living fission products drawn out through the icebreaker mainmast did not exceed ca.10^{-8} curie per litre. The air is drawn out from the mainmast at a speed about 20 m/sec. This favours an intense turbulization and mixing of active air with the surrounding atmosphere. Owing to this the specific activity of air at a distance of several tens of metres from top of the mainmast decreases down to values essentially less than MPC even in the cases of the water leaks from the primary circuit.

In normal operating conditions of the NPP on "Lenin" icebreaker the specific activity of air when leaving the mainmast is extremely low and is below the measurement limit of the high-sensitive detector (2.10^{-10} curie per litre) installed on the ship.

The solid and liquid radioactive wastes generated during the ship NPP operation are collected and stored on the ship's board in special containers and depositories depending on their specific activities and physico-chemical compositions. At the point of basement the wastes are transferred to specially equiped ships (Fig.5) for subsequent reprocessing and burial on areas especially destined for this purpouses.

The accumulated operation experience allows to content that the NPP of "Lenin" icebreaker has a highly effective system of radiation safety thanks to which the operation of this ship is fully safe for the mooring and basing sites of the icebreaker and the caravan after it as well as for the food and water resources of the sea.

3. Conclusions

We have considered the main safety problems of operation of the NPP on "Lenin" icebreaker which are discussed in the recommendations about nuclear-powered ships, the Appendix "C" of the International Convention 1960 on safety of life at seas 14 .

From the analysis of accidents on world's fleet and from the experience with operation of "Lenin" icebreaker it was concluded that a NPP may a reliable and safe ship propulsion on icebreakers. This conclusion may be also applied to other atomic ships, too, if their hulls will be characterized by a sufficient unsinkability and by an ability to protect the NPP from essential damages in collisions with other ships as it is the case with the cargo-passanger carrier "Savannah". Putting-in of atomic ships not satisfying these requirements should be considered unsafe.

It was found that the operation of the NPP on "Lenin" icebreaker is not accompanied by a radiation hazard for the following caravan of ships, for the population of harbours where the icebreaker may be stationed, and for the food and water resources of sea. In the light of the point considered above the NPP of "Lenin" icebreaker conforms to the recommendations of the International Convention of 1960.

Some new nuclear-powered icebreakers are being planned in the Soviet Union now. As the operation experience with the "Lenin" icebreaker has shown their application in Arctic is quite expedient and will allow to speed up essentially the development of the Soviet North.

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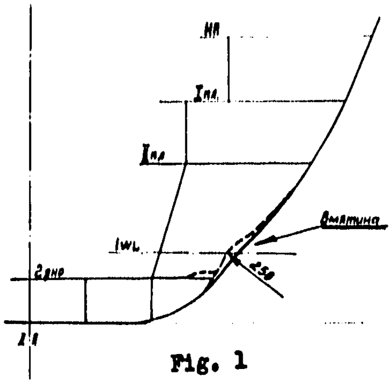

Fig. 1

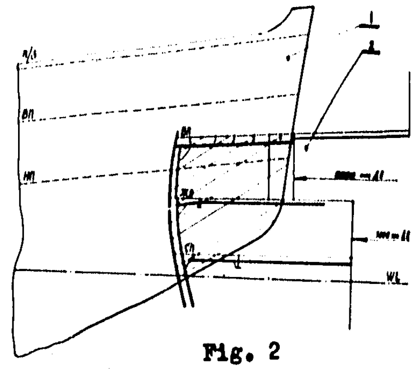

Fig. 2

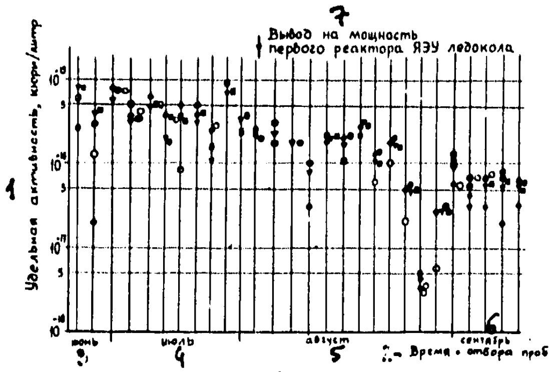

Fig. 3

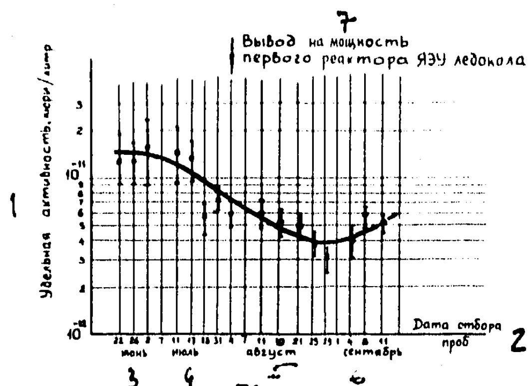

Fig. 4

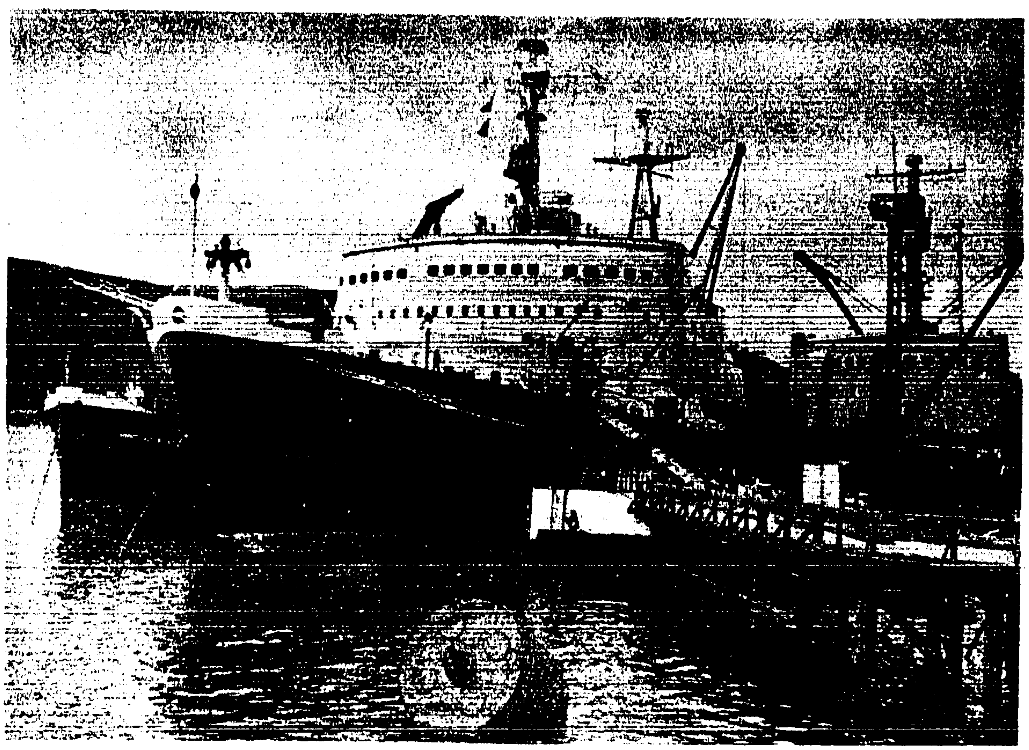

Fig. 5

Fugures

Fig.1. Damage caused to the "Lenin" icebreaker hull in a collision with an ice formation in 1961. (Cross-section along frame 41, viewed from the bow).
HP - lower deck; I пл -the first platform; II пл -the second platform; ДП - diametral plane.

Fig.2. Sketch to calculation of a hypothetic case of collision between icebreaker-type transport ship "Lena" and icebreaker "Lenin". The shaded area is the destructable part of the atomic icebreaker "Lenin" board.
1 - the bow of the transport ship "Lena"; 2 - "Lenin" icebreaker board; П/б - topgallant forecastle; ВП- upper deck; ЖП - berth deck; СП - middle deck ; НП - lower deck; ДП - diametral plane.

Fig.3. Concentration of long-living beta-active aerosols in atmospheric air in the period of mooring tests of the atomic icebreaker "Lenin" (at a distance of 500-700 m from the mooring place).
1 - specific activity, curie per litre
2 - Data
3,4,5,6 - June, July, August, September
7 - start-up first reactor of NNP

Fig.4. Concentration of beta-active substances in waters of Neva river for the period from 22 June to September 11, 1959 (average values for oll the points).
1 - 7 - See Fig.3.

Fig.5. The atomic icebreaker "Lenin" at its home port.

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